INDUSTRIAL EXPERIENCE

USE OF ROBOTICS IN CRYSTAL WARE DECORATION

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Aspects of training and using robots in cutting diamond facets on crystal ware and automated correction of the program related to deviations in product dimensions are studied. Technical and economic parameters of the process are given.

In traditional polishing an operator uses his physical force, skill, and senses to perform reciprocating, circular, elliptical, and other displacements of the article with respect to the abrasive wheel, whereas a specially trained robot can undertake all these functions and perform them with more precise positioning.

The robot complex developed and used at the Neman Glass Factory (Fig. 1) includes two main systems: controlling and executive.

The controlling system is based on microprocessor technology and contains one central processor and a controlling processor for each hinge (degree of freedom) of the robot. The display, keyboard, and control panel provide for on-time control of the decoration process and are used in program development and robot training.

The executive system consists of a robot, an SAG-3 grinder with abrasive instruments, and capturing devices, accumulating containers, and software.
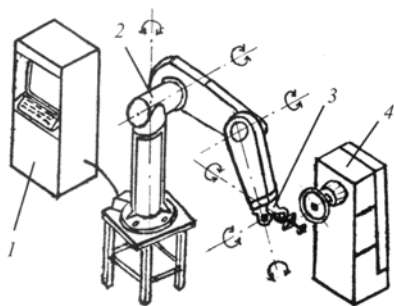
A holder is attached to the robot's hand via a flange. The processed article is fixed in the holder by vacuum. Two rigidly fixed rings serve for this purpose. The upper ring serves to ensure air-tightness in the vase cavity, and for this purpose, a soft rubber sealing is glued to the working surface of the ring, which should closely adhere to the polished edge. The lower ring is a centering device that also has a certain role in balancing the forces applied in grinding, as an additional support point absorbing these forces.

The development of a program and the training of the robot are implemented using a prototype made by manual cutting.

Examples of patterns executed on flower vases (Fig. 3) are shown in Fig. 2.

Fig. 2. Pattern elements on flower vases: *a*: *I – IV*) basic levels of vase measurement, *1 – 21*) sequence of depositing pattern elements on the vase; *b*: *I – VII*) basic vase measurement levels, *1 – 19*) sequence of depositing pattern elements on the vase.

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Fig. 1. Robotic technological complex: *1*) control system; *2*) industrial robot; *3*) holder; *4*) SAG-3 polishing machine.
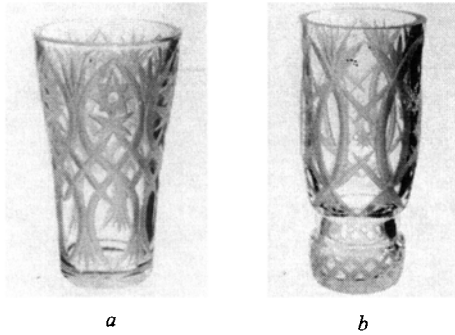
Fig. 3. Flower vases with automated diamond facet cutting in accordance with the patterns in Fig. 2a and b.

The training of the robot is implemented by means of the control panel and includes the following stages:

introducing an uncut vase into the cutting area;

imparting the needed orientation to the article (the cutting line should be within the plane of the wheel, to avoid excessive oval orientation of the facet);

storing in memory the coordinates of the starting and end points of each intermediate segment comprising the route of motion of the article;

setting the cutting depth, switching on the SAG grinder, and correcting the coordinates of the points to ensure convergence of the facet edges, i.e., lengthening or shortening them and ensuring facet intersection at the same depth, respectively, after raising or lowering a point.

Training is carried out in a single setting of the article. The distance between intermediate points was taken equal to 10 mm.

The whole surface of the article is split into a certain number of zones, each containing all elements of the pattern. In the vases presented as examples, the surface is split into 6 zones.

Automation of the decoration process requires precise repetition of dimensions from one article to another. Hand-forming technology cannot satisfy this requirement. Due to the varying thickness of inducing the forming surface, the outer dimensions of the article vary, and the wall thickness varies from article to article and within one and the same article. Moreover, there are deviations in height, lack of parallelism between the bottom and top surfaces, and ovality. Even when these deviations are within the limits of the current standard tolerances, they cause variations in the point coordinates, which results in too high or too low positioning of the pattern lines and alterations in the facet cut depth and the mutual arrangement of the facets. The magnitude of the deviations in the basic point coordinates from the coordinates adopted in the developed program can be evaluated from the data in Table 1.

In manual cutting, such deviations are compensated by visual observation of the process and the operator's skill. In order to prevent the mentioned pattern defects in automated cutting, a special program of automatic measurement of the processed article at certain basic levels with simultaneous correction of the basic-point coordinates has been developed. The basic points are the starting and end points of the main lines of the pattern, their intersections or convergences, centers of single small elements, etc. For each pattern, specific basic levels and basic points on these lines are selected. Fig. 2a and b presents the basic lines $I - VI$ and $I - VII$, respectively. There are basic points at every level, whose quantity is equal to the number of zones. Besides this, measurements are performed along the outer bottom surface to correct the height of the pattern position.

After the end of the measurement, the robot transports the vase to the cutting area, and the decoration program begins. The sequence of deposition of the elements is shown in Fig. 2. The sequence is chosen in a way to ensure minimum hand movement in going from one element to another.

TABLE 1

| Basic level | Deviation in the size of the radius, mm, at base points located in zones | | | | | | | | | | | | | | | | | |
| | Sample 1 | | | | | | Sample 2 | | | | | | Sample 3 | | | | | |
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
	Flower vase (Fig. 2a)																	
I	0.34	−0.07	−0.13	−0.26	−0.07	0.21	0.48	0.34	−0.01	−0.19	−0.41	−0.07	0.24	0.12	−0.41	−0.38	−0.10	0.09
II	0.13	−0.15	−0.24	−0.06	0.13	0.29	0.32	0.13	0.13	−0.18	−0.27	0.13	0.26	0.01	−0.43	−0.24	−0.01	0.48
III	0.45	0.00	−0.24	−0.10	0.04	0.33	0.52	0.39	0.14	−0.33	−0.36	−0.08	0.33	−0.05	−0.33	−0.33	−0.21	0.31
IV	0.36	−0.21	−0.64	−0.24	0.14	0.64	0.29	−0.03	−0.02	−0.11	−0.39	−0.08	−0.08	−0.17	−0.14	−0.11	−0.11	0.33
V	0.30	−0.45	−0.67	−0.07	0.61	0.80	0.39	−0.01	0.21	−0.01	−0.17	0.05	−0.02	−0.36	0.05	0.08	−0.14	−0.36
VI	0.34	0.13	−0.12	−0.24	−0.15	0.23	0.13	0.32	0.13	−0.18	−0.27	0.13	0.48	0.26	0.01	−0.43	−0.24	−0.01
	Flower vase (Fig. 2b)																	
I	0.60	0.07	−0.84	−0.65	0.35	0.47	0.25	−0.56	−0.09	0.41	0.60	0.82	0.16	−1.43	−1.43	−0.53	0.53	1.91
II	0.27	0.27	−0.51	−0.54	0.12	0.52	0.12	−0.35	−0.62	−0.38	−0.20	−0.09	0.71	−0.88	−1.54	−1.08	−0.20	0.96
III	0.15	−0.41	−0.41	0.00	0.65	0.44	0.00	−0.53	−0.56	−0.35	0.09	0.31	−0.06	−1.00	−0.85	−0.44	0.44	0.90
IV	−0.10	−0.51	−0.32	0.09	0.74	0.52	0.74	0.49	0.09	0.09	0.09	0.74	0.52	−0.54	−0.54	−0.20	−0.10	0.30
V	−0.51	−0.60	−0.23	0.55	0.96	0.40	0.52	0.37	−0.04	−0.04	0.37	0.57	−0.10	−0.63	−0.48	−0.26	−0.26	0.34
VI	0.47	0.60	0.07	−0.84	−0.65	0.35	0.82	0.25	−0.56	−0.09	0.41	0.60	1.91	0.16	−1.43	−1.43	−0.53	0.53
VII	0.27	−0.51	−0.54	0.12	0.52	0.27	−0.35	−0.62	−0.38	−0.20	−0.09	0.12	−0.88	−1.54	−1.08	−0.20	0.96	0.71

TABLE 2

Parameter	Vase	
	Fig. 3a	Fig. 3b
Time of base-level measurement, min/unit	2.2	2.6
Full time of the cutting program, min/unit	15.0	12.3
Amount of polished glass in relation to the initial weight, %	8.4	7.1

After the program is finished, the holder with the article returns to the initial position, and the article is released and transported to subsequent treatment operations.

In designing a pattern, one should bear in mind that its elements should be performed by an abrasive wheel of one size.

Certain technical-economic parameters of the flower vase decoration process are given in Table 2.

This technology is especially efficient in cutting facets of complicated trajectories that are hard to reproduce manually.

When robotics is used, the specific consumption of the diamond tool is reduced significantly, the consumption of acids on chemical smoothing decreases as well, the efficiency increases, and the production level is improved. Furthermore, conditions that might cause occupational diseases are eliminated, and conditions for a continuous production cycle are created.